

FORCE REFLECTING HAPTIC INTERFACE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. provisional patent application serial No. 60/093,300 filed on Jul. 17, 1998, the disclosure of which is incorporated herein by reference in its entirety. This application also incorporates herein by reference a U.S. patent application filed of even date herewith and identified by Attorney Docket No. SNS-007.

TECHNICAL FIELD

[0002] The present invention relates generally to a man/machine interface and, more specifically, to a force reflecting haptic interface.

BACKGROUND

[0003] Force reflecting haptic interfaces and associated computer hardware and software are used in a variety of systems to provide tactile sensory feedback to a user in addition to conventional visual feedback, thereby affording an enhanced man/machine interface. These systems are becoming more prevalent in such diverse areas as surgical technique training, is industrial design and modeling, and personal entertainment.

[0004] An example of a haptic interface for use in a desktop environment is disclosed in U.S. Pat. No. 5,587,937 issued to Massie et al., the disclosure of which is herein incorporated by reference. Briefly, the disclosed haptic interface defines a user reference point located, for example, proximate or within a volume of a user connection element such as a finger thimble or stylus configured to be donned or grasped by a user. Disposed between the user connection element and a spatial or reference ground are a series of mechanical transmission elements such as gimbals, linkages, and frames configured to permit substantially unrestricted movement of the connection element within a predetermined work volume of the haptic interface when in an unpowered state.

[0005] Based on the configuration and orientation of the transmission elements, multiple independent degrees of freedom may be provided. Depending on the particular application for the interface, each degree of freedom may be either powered and/or tracked, or free, being neither powered nor tracked. For example, a degree of freedom may be powered by a motor or other actuator so that, under appropriate conditions, the interface can resist, balance, or overcome a user input force along that degree of freedom. The powered axis may be active, with force being varied as a function of system conditions, or passive, such as when a constant resistance or drag force is applied. Alternatively or additionally, a degree of freedom can be tracked using an encoder, potentiometer, or other measurement device so that, in combination with other tracked degrees of freedom, the spatial location of the reference point within the work volume can be determined relative to ground. Lastly, a degree of freedom may be free, such that a user is free to move along the degree of freedom substantially without restriction and without tracking within the limits of the range of motion. The interface, in combination with appropriate computer hardware and software, can be used to provide

haptic feedback in a virtual reality environment or link a user to an actual manipulator located, for example, in a remote or hazardous environment.

[0006] Significant challenges exist in designing a force reflecting haptic interface with appropriate operational and response characteristics. For example, it is desirable that the haptic interface have low friction and weight balance such that a user's movements will not be unduly resisted and the user will not become fatigued merely by moving the connection element within the work volume. It is also desirable that the haptic interface have a high degree of resolution and be highly responsive so as to replicate, as closely as possible, an actual haptic experience. Reliability, compact size, low cost, and simplicity of design for ease of manufacture and repair also are beneficial attributes from the standpoint of commercial acceptance and appeal.

SUMMARY OF THE INVENTION

[0007] In one embodiment, a six degree of freedom force reflecting haptic interface includes a housing defining a reference ground and six structural elements connected by six joints or articulations. A first powered tracked rotary element is supported by the housing to define a first articulation with an axis having a substantially vertical orientation. A second powered tracked rotary element is mounted thereon to define a second articulation with an axis having a substantially perpendicular orientation relative to the first axis. A third powered tracked rotary element is mounted on a generally outwardly radially disposed extension of the second element to define a third articulation having an axis which is substantially parallel to the second axis. A fourth free rotary element is mounted on a generally outwardly radially disposed extension of the third element to define a fourth articulation having an axis which is substantially perpendicular to the third axis. A fifth free rotary element is mounted on a generally outwardly radially disposed extension of the fourth element to define a fifth articulation having an axis which is substantially perpendicular to the fourth axis. Lastly, a sixth free rotary user connection element in the form of a stylus configured to be grasped by a user is mounted on a generally outwardly radially disposed extension of the fifth element to define a sixth articulation having an axis which is substantially perpendicular to the fifth axis.

[0008] Three actuators and cable drives are utilized in the interface to power the first, second, and third rotary axes. Each of the cable drives includes at least one automatic cable tensioning device for preventing backlash and a grounded or ungrounded actuator capstan to prevent slippage of each cable relative to its respective actuator capstan. Cable drives on the first and second axes include cables manufactured from a braided tungsten or polymer composition including a fused blend of high modulus polyethylene fibers and liquid crystal aromatic polyester-polyarylate fibers which exhibit low creep, high strength, and long life. The third axis drive includes a braided tungsten or polymer composition cable to drive a transfer element and first and second metal cables driven by the transfer element to power the third axis. Each metal cable has a centrally disposed aluminum or stainless steel rod, or other suitably rigid member, and looped stranded stainless steel or braided tungsten cable ends. In combination, the components of the third axis drive provide high stiffness and prevent backlash in a remotely actuated, cantilevered drive.